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ORIGINAL RESEARCH ARTICLE

EFFECT OF MOISTURE CONTENT VARIATION ON THERMO-PHYSICAL PROPERTIES OF BROWN VARIETY TIGERNUT (*Cyperus esculentus*)

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ABSTRACT
Knowledge of thermophysical properties is essential to the food processing industries. The properties are useful in modeling of thermal behavior of seeds during processing operations such as frying, baking, boiling fermentation and drying. To this end, the thermo physical properties (bulk density, porosity, surface area, thermal conductivity, thermal diffusivity and specific heat capacity) of brown variety tigernut (*Cyperus esculentus*) were investigated as a function of moisture content. In this study, thermal conductivity and specific heat capacity were determined by transient state heat transfer (line heat source) and mixture methods respectively, whereas, thermal diffusivity, bulk density, porosity and surface area were determined using formula methods. The evaluation was conducted at 5 moisture levels (20, 25, 30, 35 and 40% w.b) with 5 replications. The thermal conductivity and diffusivity increased from $0.03 Wm^{-1}k^{-1}$ to $0.13 Wm^{-1}k^{-1}$ and from $7.24 \times 10^{-7} m^2s^{-1}$ to $11.06 \times 10^{-7} m^2s^{-1}$ as the moisture content increased from 20 to 40% respectively. The specific heat increased from $10.55 Jkg^{-1}K^{-1}$ to $18.75 Jkg^{-1}K^{-1}$, while the bulk density and surface area showed an increase from $421.40 kg/m^3$ to $639.80 kg/m^3$ and from $197.26 mm^2$ to $413.21 mm^2$ as moisture content increased. However, porosity decreased in value from 61.84 to 32.33% with an increase in moisture. Moisture content variation was statistically significant ($p<0.05$) on all properties. The obtained results will find use in the selection of suitable methods for processing of tigernut products, in a quality assessment of optimal modes of technological processes, and in the development of modern processing and handling equipment.

1.0 Introduction

Knowledge of thermo-physical properties is of primary importance to the food industry. This information is required to make proper design of food processing equipment such as tanks, pumps, pipes, chillers and evaporators (de Moura et al., 1998). The thermal conductivity of materials can be influenced by a number of factors such as the moisture content of the material, porosity and fiber orientation of the material (Mohsenin, 1990; Stroshine and Hamann, 1994). Several researchers including Rahman (1993) and Yang, et al. (2002) have emphasized the need for thermal properties of foods in general and seafood in particular. Thermal properties are

useful in modeling thermal behavior of seeds during thermal processing operations such as drying, boiling, baking and frying (Alagusundaram et al., 1991; Yang et al., 2002). The primary thermal properties of food and agricultural products are specific heat capacity, thermal conductivity and thermal diffusivity. Specific heat is the property needed in the estimation of the amount of energy required to change the temperature of a product, while thermal conductivity and thermal diffusivity are involved in the determination of the rate of heat transfer for efficient process and equipment design. (Aviara et al., 2003). Knowledge of thermo-physical properties is a basic condition for describing material's behavior during food processing. There is, however, dearth of information on the thermo-physical properties of tiger-nut which has limited its utilization in the food industry in Nigeria.

Tiger-nut (Cyperus esculentus var. sativus), an emergent grass- like plant (Figure 1) belonging to the sedge family, is a cosmopolitan perennial crop of the same genus as the papyrus plant commonly found in seasonally flooded wetlands (Vilmorin, 2010). It is widely distributed in the temperate zones within South Europe as its probable origin, and has become naturalized in Ghana, Nigeria and Sierra Leone (Anorn, 1992). Tiger- nut (Figure 2) is one of the earliest domesticated crops and found abundantly in Nigeria as either fresh, semi-dried or dried form in local markets and consumed as snacks in its uncooked form. Tiger nuts are grossly under-utilized due in part to paucity of information on their nutritional potential (Rita, 2009). Tigernut grows mainly in the middle belt and northern regions of Nigeria. It is known in Nigeria as'Ayaya in Hausa, 'Imumu' in Yoruba and 'Akiausa' in Igbo, and three varieties (black, brown and yellow) are cultivated (Osagie and Eka, 1998). Among these, only two varieties, yellow and brown are readily available in the market. The yellow variety is preferred over others because of its inherent properties like its large size, attractive colour and fleshier nature. The yellow variety also yields more milk, contains lower fat, higher protein and less anti-nutritional factors especially polyphenols (Okafor et al., 2003; Belewu and Abodunrin, 2005; Ebringa, 2007). The tubers contain up to 30% of non-drying oil which is used in cooking, soap making, component of beauty product, medicinally as enemas and oral medications (Shaker et al., 2009; Muhammad et al., 2011).

Figure 1: Tigernut Plant

Figure 2: Tigernut Tuber

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The selected thermo-physical properties (specific heat capacity, thermal conductivity, thermal diffusivity, bulk density, porosity and surface area) for this present study are important in many problems associated with the design of machines and the analysis of the behavior of the product during agricultural process operations such as handling, planting, harvesting, threshing, cleaning, sorting and drying. Solutions to problems in these processes involve knowledge of these engineering properties (Irtwange, 2000; Varnamkhasti et al., 2008; Tavakoli et al., 2009). Temperature and moisture present the most important parameters having clear relation to the character of physical, chemical and physiological processes in biological agricultural materials. Physical processes, above all heat and moisture transport, affect the intensity of physiological processes, nominally of breath, germination, microorganisms progress and many others and in consequence determine the final quality of food sources. The understanding of the thermal properties of food and their responses to process conditions is necessary not only because they affect physical treatment received during processing but also because they are the commonest indicators of other properties and qualities. Hence, the main objective of this study is to determine the effect of moisture content variation on the thermo-physical properties of brown variety tiger-nut.

2. Material and Methods

2.1 Sample Preparation

The brown variety of tigernut used for this study was obtained at a local market in Bauchi, Bauchi State, Nigeria. The tubers were cleaned manually to remove all foreign matters such as dirt, stones, immature and broken seeds. The initial moisture content of the samples was determined by oven drying method at 103 ºC for 48 h, as used by Sacilik et al. (2003). Selected samples were moistened with a calculated quantity of distilled water and conditioned to raise their moisture content to the desired different levels. Equation (1) was used to calculate the quantity of distilled water used according to Coskun et al. (2006).

$$Q = Wi\ \frac{(mi - mf)}{100 - mf} \tag{1}$$

Where: Q = mass of added water (kg), W_i is the initial mass of the sample (kg), m_i is the initial moisture content of the sample (%,) and m_f is the final moisture content of the sample (%,).

Five levels of moisture contents were used for the brown variety, 20, 25, 30, 35 and 40% (w.b), which were achieved by oven drying at 72 °C (recording m_c at every 15 min interval). The samples were then stored in airtight polythene and kept at 5 °C in a refrigerator for a week to achieve uniform moisture distribution within them.

2.2 Determination of Bulk Density

Bulk density is the ratio of the mass of a sample of seed to total volume (Shafiee et al., 2009). Bulk density for all the samples were determined by filling an empty 300 mL beaker with tiger-nut seeds and weighing it. The weight of the seeds was obtained by deducting the weight of the empty beaker from the weight of the seed-filled beaker. To achieve uniformity in bulk density, the beaker was tapped 10 times for the seeds to consolidate in the beaker (Ahmadi et al., 2009). The beaker was filled with seeds dropped from a 15 cm height and a sharp–edged, flat metal file was used to remove excess seeds to level the surface at the top of the graduated beaker (Nalbandi et al., 2010). Bulk density was calculated using Equation (2).

$$\rho b = m/v \tag{2}$$

Where, ρb, bulk density, (kg/m^3), m, mass of sample bulk, (kg) and v, volume occupied by seed bulk, (m^3).This was replicated five times and the mean calculated for each sample.

2.3 Determination of Porosity

The porosity (ε) values were calculated from the values of true density and bulk density using the relationship in Equation (3) as reported by Bup et al. (2013).

$$\text{Porosity } (\varepsilon) = (1 - \frac{\rho b}{\rho t}) \times 100 \tag{3}$$

Where ρb, bulk density (kg m^{-3}), ρt, true or particle density (kg m^{-3})

2.4 Determination of Surface area

The surface area (Sa) was determined by analogy using Equations (4) and (5) as reported by Balami et al. (2014).

$$Sa = \frac{\pi d a^2}{2a - d} \tag{4}$$

$$Sa = \frac{\pi d a^2}{2a - d} \tag{5}$$

Where, a, major diameter (mm), b, intermediate diameter (mm), c, minor diameter, (mm) and d, geometric mean diameter, mm)

2.5 Determination of Specific Heat Capacity

The method of mixtures has been the most common technique reported in the literature for measuring the specific heat of agricultural and food materials (Singh and Goswani, 2000; Nouri Jangi et al., 2011). For the determination of specific heat in this study, the method of mixtures was used. Sample of brown variety tiger nut of known mass, temperature and moisture content was dropped into a copper calorimeter containing water of known mass and temperature. The calorimeter was well insulated so as to prevent heat loss to the room in which the experiment was performed. The mixture was stirred continuously using a glass rod stirrer. The equilibrium (final) temperature was noted and the specific heat determined using Equation (6) as used by Aviara and Haque (2001).

$$Cs = \frac{(McCc + MwCw)\,[Tw - (Te + tR)]}{\text{Ms}\,[(\text{Te}+\text{tR}) - Ts]} \tag{6}$$

where: C_C, C_S and C_W are the specific heats of calorimeter, sample and water, respectively (J kg^{-1} K^{-1}), M_C, M_S and M_W are the masses of calorimeter, sample and water (kg), respectively, R is the rate of temperature fall of the mixture after equilibrium (K s^{-1}), Te is the equilibrium temperature of the sample and water mixture (K), T_S, and T_W are the initial temperatures of sample and water, respectively (K), and t is the time taken for the sample and water mixture to come to equilibrium (s). The term tR accounts for the heat of hydration and heat exchange with the surroundings.

2.6 Determination of Thermal Conductivity

The thermal conductivity of the seeds was determined at five different moisture levels, using the transient line heat source method assembled in a thermal conductivity probe. The probe was passed through the center of the seed and a fall in temperature occurred. A fall in temperature

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continued until a constant temperature was obtained. A rise in temperature occurred after a constant temperature period and at this point, the time was taken against the temperature. The thermal conductivity was calculated from Equations (7) and (8) as reported by Sadiku and Bamgboye (2014):

$$k = Qln\,(t_2 - t_0)/\,(t_1 - t_0)/4\pi\,(T_2 - T_1) \qquad (7)$$

$$Q\ Q = I^2 R \qquad (8)$$

Where: k, thermal conductivity of sample (W/m°C), Q, power dissipation by heater wire (W/m), t_1, time since probe heater was energized (s), t_2, time since probe heater was energized (s), t_0, time correction factor (s), T_1, temperature of probe thermocouple at time t_1 (°C) and T_2, temperature of probe thermocouple at time t_2 (°C), I, electric current in A and R, electric resistance (ohm/m).

2.7 Determination of Thermal Diffusivity

The thermal diffusivity was calculated using experimental values of specific heat, thermal conductivity and bulk density using Equation (9) as reported by Vijay (2013).

$$\propto = k/\rho c_p \qquad (9)$$

Where: α is the thermal diffusivity ($m^2\ s^{-2}$), k is the thermal conductivity ($Wm^{-1}{}^{\circ}C^{-1}$), ρ is the bulk density (kg/m^3) and C_p is the specific heat ($kJkg^{-1}\ {}^{\circ}C^{-1}$)

2.8 Statistical Analysis

The data generated were analyzed using the Analysis of variance (ANOVA) to determine which treatment effect was significant or not and Tukey's studentized range ($p < 0.05$) was used to determine significant difference between means using statistical analysis system (SAS9.2) 2010.

3.0 Results and Discussion

3.1 Results the values of physical and thermal properties of tigernut at varying moisture

The mean values and standard deviations of bulk density, porosity, surface area, specific heat, thermal conductivity and thermal diffusivity variation with moisture content of brown variety tigernut is shown in table 1. It is observed that values of the properties increases as moisture increases for the properties with the exception of porosity, which decreases as moisture increases.

Table 1: Thermophysical values at varying moisture content of Brown variety tigernut

Property	Unit	Moisture Content (%)				
		20	25	30	35	40
Bulk Density	kg/m^3	421.4d±2.61	475.2c±0.45	564.8b±1.10	620a±0.71	639.8a±1.10
Porosity	%	61.84h±3.16	52.27g±2.46	48.52f±1.83	33.47e±2.39	32.33e±1.22
Surface Area	mm^2	197.26l±28.68	211.07k±10.73	221.93k±26.98	298.21j±27.24	413.21i±34.07
Specific Heat Capacity	$kJkg^{-1}\ {}^{\circ}C^{-1}$	10.55o±0.18	12.37o±0.15	14.39n±0.17	15.92n±0.61	18.75m±0.45
Thermal Conductivity	$Wm^{-1}{}^{\circ}C^{-1}$	0.032e±0.00	0.056d±0.00	0.081c±0.00	0.106b±0.00	0.133a±0.00
Thermal Diffusivity	$x10^{-8}\ m^2\ s^{-2}$	7.24g±0.13	9.45f±0.43	9.94f±0.34	10.59f±0.48	11.06f±0.36

Values in the same row followed by different letters are significantly different (p<0.05).

Table 2 is the analysis of variance on the variation of moisture on the physical and thermal of brown variety tigernut.

Table 2: ANOVA on variation of moisture content on thermal properties of Brown tigernut

Source	Df	SS	MS	F- Value	Pr > F
Properties (BV)	5	6020489.673	1204097.935	9922.34**	< .0001
Replication	4	349.557	87.389	0.72ns	0.5799
Moisture Content (MC)	4	93925.097	23481.274	193.5**	< .0001
Properties* MC	20	247091.85	12354.592	101.81**	< .0001

**highly significant, ns = not significant

3.2 Discussion

3.2.1 Effect of moisture content on bulk density

Table 1 presents the variation of bulk density with moisture content for brown variety tigernut. The bulk density of brown variety tigernut increased linearly from 421.4 to 639.8 kgm^{-3} as moisture content increased from 20 to 40% as presented in table 2.The increase in the bulk density was due to increase in the mass of tigernut with a gain in moisture which was higher than the volumetric expansion of the bulk (Pradhar et al., 2008). The effect of seed moisture content on bulk density was statistically significant ($p<0.05$). Similar increasing bulk density with variation in moisture content was reported by Baryeh and Mangope (2002) for QP – 38 variety pigeon pea, Kingsley et al., (2006) for dried pomegranate seeds, Nikoobin et al. (2009) for chickpea seeds and Oyerinde and Olalusi (2013) for two varieties of tigernut.

3.2.2 Effect of moisture content on porosity

Porosity of materials usually is dependent on the bulk as well as the true densities (Oyerinde and Olalusi, 2013). The porosity of the brown variety tigernut decreased from 61.84 to 32.33% as moisture content varied from 20 to 40%. Similar trend was reported by Oyerinde and Olalusi (2013) for two variety tiger-nut. This decrease may be due to the changes in the mass and density value of the tiger-nut as it absorbed water. Higher porosity at low moisture content indicates that high number of tigernut tubers can be stored at lower moisture content than at high moisture content due to an increase in the cohesion of the cell structure of the tigernut as moisture increases (Abano and Amoah, 2011). Table 2 presents the variation of porosity with moisture content for the brown variety, and the effect of moisture on porosity was statistically significant ($p< 0.05$) except between 25 and 35%moisture content.

3.2.3 Effect of moisture content on surface area

The effect of moisture content on the surface area of the tigernut is presented in Table 2. The surface area increased linearly from 197.26 to 413.21 mm^2 as the moisture content varied from 20 to 40%. The values for surface area were statistically significant ($p < 0.05$) from 30 to 40%, however, a reverse trend was reported for black variety tigernut by Abano and Amoah (2011). Hence, the results may be due to the different shape assumption of the tuber and this suggests that it's advisable to store the tubers at lower moisture content when the surface area is lowest for the tuber to present less surface area for moisture absorption during storage (Abano and Amoah, 2011).

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3.2.4 Effect of moisture content on specific heat capacity

Specific heat capacity is needed in estimating the amount of heat energy required to change the temperature of material by 1°C (Sadiku and Bamgboye, 2014). The specific heat capacity of brown variety tigernut increased from 10.55 to 18.75 kJkg^{-1} °C^{-1} as moisture content increased from 20 to 40% and the result (Table 2) was not statistically significant ($p > 0.05$). Similar trend was reported for Parkia seeds (Sadiku and Bamgboye, 2014) which indicated an increase from 2.74 to 4.38 kJkg^{-1} °C^{-1} for a moisture increase of 5.9 to 28.2%. The increasing trend in specific heat capacity with moisture content correlates with work done by other researchers on Cumin seeds (Singh and Goswani, 2000), Lentil seeds (Tang, et, al., 1991), Potato (Wang and Breman, 1993) and Pistachio nuts (Razavi and Taghizadeh, 2007), all of which shows similar trend with brown variety tigernut. The increased specific heat capacity with moisture is due to high specific heat of water compound to dry material (Sadiku and Bamgboye, 2014).

3.2.5 Effect of moisture content on thermal conductivity

Thermal conductivity is the possibility of transmitting heat within seeds in bulk. Hence, the thermal conductivity of brown variety tigernut increased from 0.032 to 0.133 Wm^{-1}°C^{-1} as moisture increased from 20 to 40%, this indicates that heat transmission within the tigernut is less when dried and more if wet (Sadiku and Bamgboye, 2014). The increase in thermal conductivity as moisture increased was because the increased moisture, increased the bulk thermal conductivity as moisture has higher thermal conductivity than that of air (Vijay, 2013). Similar results were reported for borage seed by Yang et al. (2002), soya bean pod by Mohsen et al. (2013), coriander seed (Vijay, 2013) and three varieties of melon (Isa et al., 2014). The result for thermal conductivity of brown variety tigernut is in agreement with the findings of Sadiku and Bamgboye (2014) for Parkia seeds. The effect of moisture content on the thermal conductivity of tigernut was presented in Table 1, though the moisture effect was not statistically significant ($p > 0.05$). The relationship between thermal conductivity and moisture content of tigernut was linear (as shown in Table 1).

3.2.6 Effect of moisture content on thermal diffusivity

The variation of thermal diffusivity with moisture content is presented in Table 2. Thermal diffusivity of tigernut increased from 7.24 x 10^{-8} m^2 s^{-2} to 11.06 x 10^{-8} m^2 s^{-2} as the moisture content increased from 20 to 40%. The increase in thermal diffusivity at different moisture content may be due to the fact that the value of bulk density decreased at these moisture levels (Singh and Goswani, 2000). Bamgboye and Adejumo (2010) also reported similar results for Roselle seeds. The results for the thermal diffusivity of brown variety tigernut is in agreement with the findings of Aviara and Haque (2001), that thermal diffusivity of sheanut kernel increased with moisture content, but disagreed with the findings of Subramanian and Viswanathan (2003), for minor millet grain and flour, Singh and Goswani (2000), for cumin seeds and Aremu and Fedele (2010), whose obtained values for doum palm fruits showed an inverse relationship with moisture content. This ascending and descending trend of relationship between moisture content and thermal diffusivity is because the magnitude of thermal diffusivity depend on the combined effect of thermal conductivity, bulk density and specific heat capacity (Yang et al., 2002).

3.2.7 Analysis of Variance (ANOVA)

Analysis of variance (ANOVA) was conducted to ascertain the significant effect of moisture content variation on the thermophysical properties (Specific heat capacity, Thermal conductivity, Thermal diffusivity, Bulk density, porosity and Surface area) of brown variety tigernut as shown in Table 2. The results of the ANOVA showed that there were highly significant differences ($F = 9922.34$, $p = 0.0001 < 0.05$) among the values obtained for the properties of brown variety tigernut. This indicates that the values of the properties were highly influenced by moisture content. The effect of replication from the ANOVA was not significant ($F = 0.72$, $p = 0.599 > 0.05$), this may be due to minimized error in the performance of the experiment in the laboratory. The variation in moisture content was highly significant ($F = 193.5$, $p = 0.0001 < 0.05$), this means as moisture increased, the values of thermophysical properties either increased or decreased. However, the interaction between the properties and moisture content indicate a highly significant difference ($F = 101.81$, $p = 0.0001 < 0.05$). The interaction effect shows that the relationship between tigernut properties and moisture content depends on the amount or variation of the moisture content.

4. Conclusion

Thermophysical properties of brown variety tigernut (Cyperus esculentus) were determined for the typical ranges of moisture content. The results showed the significant variations in thermo-physical properties values with changing moisture content. All the properties increased as the moisture level increased, with the exception of porosity, which reduced as moisture increased. The bulk density and surface area increased from 421.40 kg/m^3 to 639.80 kg/m^3 and from 197.26 mm^2 to 413.21 mm^2 as moisture content increased. However, porosity decreased from 61.84 to 32.33% with an increase in moisture. The specific heat increased from 10.55 Jkg^{-1}K^{-1} to 18.75 Jkg^{-1}K^{-1}, while the thermal conductivity and diffusivity increased from 0.03 Wm^{-1}K^{-1} to 0.13 Wm^{-1}K^{-1} and from 7.24 x 10^{-7}m^{2}s^{-1} to 11.06 x 10^{-7}m^{2}s^{-1} as the moisture content increased from 20 to 40% respectively.

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